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MONITORING THE LEVEL OF COSMIC RADIATION DURING THE FLIGHTS OF  
VOSTOK-3, VOSTOK-4, VOSTOK-5 AND VOSTOK-6

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ABSTRACT

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The effects of solar activity and magnetic storm, and artificial factors (atomic explosions) are examined. Differences in radiation dosages and composition are compared in many flights with varying parameters, as are readings from various on-board apparatus. Tissue doses of several cosmonauts under varying conditions are compared.

*Autho*

During the flights of Soviet Vostok-type spacecraft, the cosmonauts /40\* are exposed to the effects of primary cosmic radiation (PCR) and radiation from the Earth's radiation belts. There also exists a definite probability of irradiation of the ship's crew by corpuscular radiation connected with solar flares. Radiation conditions on the flight paths of Vostok-type spacecraft were first investigated in detail during the flights of the second and third Soviet orbital spacecraft (refs. 1, 2).

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<sup>1</sup> Report presented at the 5th International Symposium on Space Research (COSPAR), Florence, 1964.

\*Numbers given in the margin indicate the pagination in the original foreign text.

It has been established that for flights on an orbit inclined at  $65^\circ$  at altitudes of 200 to 300 km, the dose inside the ship does not exceed 8 mrad/24 hrs in the absence of radiation connected with solar flares. Radiation reaching the ship's interior is made up of: (a) charged particles of cosmic origin (both primary and secondary), amounting to 80 percent of the dose; (b)  $\gamma$ -radiation accompanying these charged particles and bremsstrahlung generated in the skin of the spacecraft by electrons from the Earth's radiation belts, 15 percent of the dose; and (c) protons from the inner radiation belt, about 5 percent of the dose.

The biological equivalent of this dose at the highest estimate does not exceed 50 mber/24 hrs, a value quite within permissible limits.

It is for this reason that on the subsequent flights of the 4th and 5th orbital spacecraft and the Vostok-1 and Vostok-2 spacecraft, only dose control measurements by means of individual dosimeters were made, the data being processed on return to the Earth. The doses measured in the course of these flights agreed with data obtained earlier (refs. 3 and 4).

On later flights of longer duration by Vostok-type spacecraft, it became necessary to introduce on-board monitoring equipment capable of recording /41 the level of radiation inside the cosmonaut's cabin and reporting it telemetrically to Earth. As the duration of flight along such trajectories increased, the probability of dangerous radiation due to solar flares (averaging 7 percent/week for years falling between solar activity maximums and minimums) became greater. Thus, this radiation monitoring equipment was basically designed to record solar flare emissions and total dose. In addition, the equipment was to transmit control signals when total doses were reached which endangered the health of the cosmonaut.

The dosimetric equipment consists of a sensor (a gas discharge counter for nuclear radiation) and a memory circuit. The memory permits the accumulation of total dose information from 1 mrad to 100 rad. This provides a basis for an emergency landing decision in case of dangerous increases in the level of radiation inside the spacecraft.

Solar activity was followed by a team of observers prior to and during the flights of the Vostok-3, Vostok-4, Vostok-5 and Vostok-6 spacecraft. This team received data from various points of the Soviet Union where continuous optical, magnetic, and radio observations of the sun were performed at astrophysical observatories and solar physics station. In addition, at a number of stations direct observations on radiation intensity in the upper atmosphere were conducted by space radiosondes. These observations provided information on the penetration of corpuscular radiation connected with solar flares into given magnetic latitudes. All information from the solar activity observation team and from the on-board monitoring equipment was fed to a scientific coordination center where it was processed. This information made it possible to make decisions on conducting the flight and its subsequent program.

Not long before the flight of the Vostok-3 and Vostok-4 spacecraft on 9 July 1962, the United States conducted a high-altitude thermonuclear explosion in the area of the Johnston Island in the Pacific Ocean. The artificial radiation belt formed as a result of this explosion led to an increase in radiation intensity in space, including altitudes around 300 km, especially in the region of the Brazilian magnetic anomaly. At the start of August 1962, the immediate estimates of the radiation level on the suggested flight path of the Vostok-3 and Vostok-4 spacecraft were contradictory. Therefore, radiation conditions at the above-mentioned altitudes were measured directly. On 28 July 1962 the

Kosmos-7 satellite was placed into an orbit with an inclination of  $65^{\circ}$ , an apogee of 369 km and a perigee of 210 km (ref. 5). Analysis of information obtained from detectors installed on this satellite indicated that during the flight, radiation intensity substantially exceeded the "background" values which had been determined from the second and third spacecraft (refs. 1 and 2) and from Kosmos-4 satellite. Thus, the counting rate of the STS-5 counter on the second and third spacecraft averaged  $2.1 \text{ impulse} \cdot \text{cm}^2 \cdot \text{sec}$  and the maximum counting rate of this detector did not exceed  $30\text{-}35 \text{ impulse} \cdot \text{cm}^2 \cdot \text{sec}$ .

According to data from the STS-5 detector on Kosmos-7, the average counting rate was  $7 \text{ impulse} \cdot \text{cm}^2 \cdot \text{sec}$  and in several regions attained  $250 \text{ impulse} \cdot \text{cm}^2 \cdot \text{sec}$ . According to our data, the absorbed dose rate inside the second spacecraft was  $3 \text{ mrad}/24 \text{ hrs}$  at the equator and about  $40 \text{ mrad}/24 \text{ hrs}$  in the vicinity of the Brazilian and South Atlantic anomalies (with an average /42 dose rate of approximately  $8.5 \text{ mrad}/24 \text{ hrs}$ ). The average dose rate on the Kosmos-7 satellite was  $55 \text{ mrad}/24 \text{ hrs}$ , increasing to  $1.2 \text{ rad}/24 \text{ hrs}$  in the vicinity of the Brazilian anomaly. (Data on the comparative dose rates were extrapolated taking the difference in detector screening into account.) Apparently, in the first week after the nuclear explosion of 9 July 1962, these values were considerably larger, since the average decay rate of the artificial belt at the indicated altitudes was on the order of days (except for the immediate vicinity of the Brazilian anomaly, where the injected particles had a longer lifetime). The planned flight altitude of Vostok-3 and Vostok-4 was lower than that of the Kosmos-7 satellite (apogee of 235 km instead of 369 km). Therefore, regardless of the increased radiation rate in space due to formation of the artificial radiation belt, the group flight of cosmonauts A G. Nikolayev and P. R. Popovich was safe with respect to radiation, provided that no large flare of solar cosmic rays occurred during the flight.

On 11 August 1962, the Vostok-3 was orbited with a perigee of 180 km and an apogee of 235 km. The orbit was inclined at an angle of  $65^{\circ}$  from the equatorial plane. The Vostok-4 was orbited on 12 August 1962 with the same parameters. Figure 1 shows the increase of absorbed dose during the flights of the Vostok-3 and Vostok-4. The increase in total dose with time was identical for the Vostok-3 and Vostok-4. The average counting rate of the detector on the Vostok-3 was  $2.64 \cdot 10^5$  impulse  $\cdot$  cm<sup>2</sup>  $\cdot$  sec per 24 hrs (a dose of 17 mrad/24 hrs); the same absorbed dose rate value was obtained from the Vostok-4. The total absorbed dose received during the flight was 67 tissue mrad for A. G. Nikolayev, and 50 tissue mrad for P. R. Popovich.

If the relative biological effectiveness (RBE) of radiation components making up the total dose is estimated, then, based on maximum values (an RBE of 7 for PCR and an RBE of 1 for other types of radiation) the dose rate for these flights expressed in biological equivalent roentgens is 30 mber/24 hrs, and the doses received by A. G. Nikolayev and P. R. Popovich during the entire flight were 120 and 90 mber, respectively. Such radiation levels are not dangerous to the health of the cosmonauts. /43

The Vostok-5 and Vostok-6 spacecraft were orbited as artificial earth satellites on 14 and 16 June 1963. Vostok-5 had an apogee of 222 km and a perigee of 175 km; Vostok-6 had an apogee of 231 km and a perigee of 181 km. Their orbits were inclined at an angle of  $65^{\circ}$  from the equatorial plane. The on-board dosimetric monitoring device was identical with that used on Vostok-3 and Vostok-4.

The flights of Vostok-5 and Vostok-6 took place under relatively quiet solar and geomagnetic conditions. Immediately prior to the flight, from 10 to 13 June, the solar magnetic field configurations became more complicated, some increase was observed in radio noise in the centimeter band, and the sudden



Figure 1. Cumulative absorbed dose in the Vostok-3 and Vostok-4 spacecraft during flight.

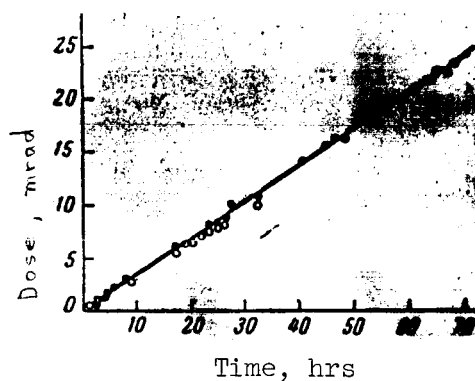


Figure 2. Plot of readings from on-board dosimeters during the first 70 hours of flight of the Vostok-5 and Vostok-6.

onset of a small magnetic storm was recorded. All of these circumstances indicated the possibility of the appearance of a solar flare. However, the flare of a power of approximately 2 balls, observed on 12 June, was not accompanied by the appearance of any noticeable quantity of solar protons in circumterrestrial space. Figure 2 shows readings of the on-board dosimeters during the first 70 hours of flight. Data for Vostok-5 are indicated by the light circles and on Vostok-6 by the solid circles. Flight duration for the two vehicles was counted from the same time. Both groups of points are consistently close to one straight line corresponding to the measured dose rate of 8 mrad/24 hrs. Some decrease of the dose rate for Vostok-5 and Vostok-6 from the dose rate

for the Vostok-3 and Vostok-4 indicates an essential decrease in the effect of the artificial radiation belt at altitudes of 200 to 300 km.

Evaluation of the tissue doses received by the cosmonauts during this flight gives the following values: 50 mrad for V. F. Bykovskiy and 30 mrad for V. V. Tereshkova.

These dose values are also safe for cosmonauts.

In Conclusion, it should be noted that Vostok type spacecraft were designed with cabin shielding sufficient to prevent penetration by a part of cosmic radiation and affording considerable protection against radiation from the artificial radiation belt. In addition, in case of a sharp deterioration of radiation conditions, the cosmonauts were provided with special radioprotective, chemical agents for protection against the radiation effects.

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